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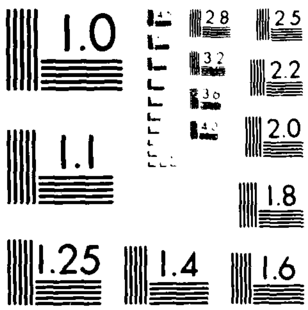

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US Army Corps of Engineers

AD-A135 745

TECHNICAL REPORT GL-83-16

(2)

REPAIR AND RESTORATION OF PAVED SURFACES; FY 82, PHASE II, BACKFILLING OF CRATERS

by

Victor C. Barber

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

October 1983

Interim Report

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The purpose of Phase II of REREPS (repair and restoration of paved surfaces) is to evaluate previously developed techniques and materials and to conduct necessary studies to determine the most beneficial backfill material. The study is to include new materials and innovative methodology to the greatest practicable extent. Compaction requirements are to be analyzed by comparison with existing requirements as modified by REREPS results to date. Specific compaction requirements include a quantification of compaction
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requirements versus depth below the load as well as subgrade compaction versus pavement strength and stiffness. Another specific requirement is to study the applicability of the sand grid support concept. In addition, other new methods and materials will be reviewed, developed, and/or introduced, as appropriate.

This study constitutes partial completion of these objectives. An investigative research effort has been made to review the status of REREPS development to data. Conclusions are that:

a. A significant reduction in current rigid or flexible pavement compaction requirements for backfill of a crater is not feasible and does not warrant further investigation.

b. The concept of reduced compaction for conventional pavements through use of current criteria for heavy-load pavements over soft soils is a possible alternative to in-crater compaction.

c. Specialized, highly competent in-crater compaction equipment is essential for the compaction of crater backfill to support conventional pavements.

d. The concept of compaction elimination or significant reduction by using synthetic backfill and pavement materials, earth reinforcing, lightweight modules, and crater-spanning techniques is a potential solution to the crater-repair problem.

e. The employment of pile foundations or free-span bridging systems is a potential solution.

PREFACE

The investigation reported herein is an ongoing one and is under the sponsorship of the Office, Chief of Engineers, U. S. Army, and is being conducted under Project AT40, Task CO, Work Unit 002, "Repair and Restoration of Paved Surfaces (REREPS)," during FY 1982. Dr. Clemens Meyer was Technical Monitor for OCE. The Geotechnical Laboratory (GL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., conducted the study.

Dr. W. F. Marcuson III was Chief, GL, and Dr. T. D. White was Chief, Pavement Systems Division (PSD), during this period. Dr. G. M. Hammitt was Program Manager for REREPS. This study and reporting were conducted by Dr. V. C. Barber, PSD.

Commander and Director of WES during the course of this study and report preparation was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENTS

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	0.0254	metres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6894.757	pascals

REPAIR AND RESTORATION OF PAVED SURFACES
FY 82, PHASE II, BACKFILLING OF CRATERS

PART I: INTRODUCTION

Background

1. The U. S. Air Force (USAF) has the responsibility for emergency war-damage repair of USAF Air Base facilities, including pavements and structures. The USAF traditionally uses landing mat crater-repair kits for emergency pavement repair. All repairs which exceed the organic capability of the USAF are the responsibility of the U. S. Army. The Army is assigned the responsibility of developing improved repair and restoration systems for paved surfaces (referred to as REREPS) that are responsive to variation in damage levels from aggressor attacks and in Allied Forces operational requirements. The areas to be evaluated include materials, equipment, and procedures utilized in a way to minimize personnel and equipment requirements, repair time, and cost as well as to maximize the length of service of the repair.

2. This interim report partially addresses the repair and restoration of war-damaged runways both in terms of emergency repairs and more permanent repairs.

3. The 18th Engineer Brigade in West Germany, the WES, the USAF Engineering Services Center (AFESC), and other agencies have respectively worked toward solutions to the REREPS problem. Studies were conducted on the applicability of regulated-set concrete for solving the REREPS problem (Hutchinson, in preparation). Results showed that regulated-set concrete was not an optimum solution. Subsequent studies were conducted at WES to evaluate several alternative potential REREPS solutions (Alford 1981 and Cooksey 1981). Although the results of these studies were generally inconclusive, gravity grouts and crushed-stone methods were considered to have merit. Additionally, rigid pavement load-transfer devices were developed and evaluated (Cooksey 1981). However, the test items were designed in a manner that precluded the need for load transfer; therefore, the value of their performance has not been established.

Purpose

4. The purpose of Phase II of REREPS is to conduct an evaluation of previously developed techniques and materials and to conduct necessary studies to determine the most beneficial backfill material. The study is to include new materials and innovative methodology to the greatest practicable extent. Compaction requirements are to be analyzed by comparison with existing requirements as modified by REREPS results to date. Specific compaction requirements include a quantification of compaction requirements versus depth below the load as well as subgrade compaction versus pavement strength and stiffness. Another specific requirement is to study the applicability of the sand grid support concept. In addition to these stated objectives, other new methods and materials will be reviewed, developed, and/or introduced, as appropriate. The purpose of this interim report is to set forth results of investigative research conducted from 1 February to 1 July 1982.

Scope

5. This study constitutes partial completion of the objectives of Phase II of REREPS. An investigative research effort has been made to review the status of REREPS developments and to set forth new concept proposals so that field research can be pursued at the earliest possible date.

PART II: COMPACTION REQUIREMENTS

Compaction Considerations in Pavement Design

6. A primary objective of this effort is to investigate the phenomenon of compaction of subgrade materials in a crater prior to placement of a pavement. The need has been identified to reduce crater-repair time and increase performance through more rapid compaction of a reduced-compaction effort. Any rational approach to a problem of this type entails a consideration of current criteria and their underlying rationale.

Purpose of compaction

7. Compaction requirements (or criteria) are primary design parameters in the design of flexible and rigid pavements. The purpose of compaction (Yoder and Witczak 1975) is to provide strength which is directly related to relative density of a soil material. Additionally, and especially important in airfield design, high compaction efforts are required to guard against subsequent consolidation, or more simply, additional compaction under load which results in undesirable runway roughness. Therefore, it is essential to consider any potential compaction reduction time from the point of view of incorporating certain strength loss and increased pavement deformation into the design of crater repairs.

Basis for current criteria

8. Numerous procedures exist for the design of flexible and rigid pavements in the current state-of-the-art (Yoder and Witczak 1975). These procedures generally fall into three main categories, namely theoretical or rational, empirical, and a combination of theoretical or rational procedures underpinned by empirical data. The Corps of Engineers (CE) design procedures are of the last type. The empirical data that are a basis for the design values of density, strength, thickness, etc., play a significant role and allow little room for arbitrary reduction.

Current compaction criteria

9. Current subgrade compaction criteria for fill-section subgrades to support rigid pavements are not less than 90 percent of modified AASHTO density (CE 55) (Department of the Army 1970). This value is larger for some base course materials and is subject to change for different loadings and traffic areas. A complete definition of compaction requirements for rigid

pavements is given in the rigid-pavement design manual TM 5-824-3. Current subgrade, subbase, and base-course compaction criteria for flexible airfield pavements are similarly 90 percent modified AASHTO density (CE 55), or greater depending upon several factors such as material type, application, loading, and traffic area (Departments of the Army and Air Force 1969).

Prerequisites to Compaction Reductions

10. TM's 5-824-2 and 5-824-3 and Yoder and Witczak can be cited as examples to illustrate the basis and criteria for compaction. Any program to significantly reduce the current criteria would necessarily require a strong data base or a theoretical design procedure that would give pre-emptive credence to such reductions. Since such prerequisites are not readily forthcoming, and in all probability would not refute the current state-of-the-art, an attempt to significantly reduce the criteria is not feasible.

Alternatives to Criteria Reduction

11. The research alternatives to reduced compaction criteria are several, and some of them show potential for easing the problem of achieving adequate subgrade support in bomb-crater backfill materials. Chief among the options are as follows:

- a. Utilization of high-quality materials that exhibit high strengths and densities with relatively little compaction effort.
- b. Application of minimal compaction effort and designing pavements for the resultant low-support values.
- c. Construction of subgrades, subbases, and base courses from materials that require little or no compaction.
- d. Construction of pavements that require little or no subgrade support.
- e. Development of sophisticated in-hole compaction equipment that will provide for rapid and complete compaction.

These five generalized options sufficiently delineate the categories of potential solutions to the crater-backfill problem. Options a. and b. are currently feasible within the framework of existing design procedures and can be pursued through field testing. Options c., d., and e. generate a requirement for material, methodology, and equipment research. This research effort, to date, has chiefly consisted of considerations in the areas of options c., d., and e., and will be treated in the remainder of this report.

PART III: NEW CONCEPTS

Introduction

Current status of technology

12. Most research to date has been concentrated upon the rapid repair of bomb craters using conventional concepts that have been adapted to this specialized need. Extensive work has been accomplished in the general areas of materials, equipment, and methodology. To date the most promising solution to the rapid repair problem appears to be that of crushed stone pavement which is currently considered the interim solution to emergency repair needs. Most research conducted has consisted of a broad approach where material, equipment, and methodology have been combined as a single variable. It is essential at this stage of this multiagency effort to reassess the requirements and the obstacles to meeting them.

Definition of the problem

13. If the administrative factors, cost factors, combat area trauma, and associated problems are eliminated, the crater problem can be viewed solely as an engineering problem. In the engineering context, the problem can generally be divided into one of material handling, cleanup, rapid backfilling, and rapid paving. The latter two, rapid backfilling and paving, can be further defined as rapid backfilling and paving in a manner to provide adequate performance within designated time frames.

Isolation of research problems

14. A survey of the research and its results to date show that two specific problems plague the crater repair research effort, namely, the compaction of subgrade materials in the crater, and the rapid installation of heavy pavement materials. These materials can be either prefabricated, installed and compacted, or installed in some liquid form. The weight of these materials generates a problem by requiring heavy-duty transporters and material handlers of various types.

Elimination of Compaction

Backfill materials

15. One solution to the compaction problem is the complete elimination

of the need to compact by the use of synthetic materials that require no compaction, as will be discussed later in this report. An alternative solution is the utilization of uniformly graded natural materials that achieve optimum particle orientation, or density, by an easily applied vibration technique.

Earth reinforcement

16. Research has been accomplished throughout the research community in the area of earth reinforcement through the use of grids, geotextiles, and reinforcing meshes. These concepts are worthy of consideration with respect to reduction of compaction in significant amounts.

Crater spanning

17. Another concept that has been considered and tentatively rejected is that of crater spanning, bridging, or semibridging. Although admittedly relatively unattractive as a concept, additional consideration should be given to the concept, as potential does exist.

Compaction Equipment

18. If conventional pavement support through compaction of subgrade materials to existing specifications is to remain a viable alternative, new equipment must be developed and made available to military units. Although work has been done by some equipment manufacturers, there is no simple machine currently available that is capable of placing the necessary compaction effort on all lifts of a crater backfill in the required time.

PART IV: NEW MATERIALS AND TECHNIQUES

Introduction

19. New materials and techniques have been tentatively generated and are discussed herein. Although some of the materials and techniques are not new, they are considered worthy of further evaluation. Some of the materials and concepts are currently scheduled for testing in upcoming prototype tests, while others are being considered.

Earth Reinforcing

Structural grids

20. Structural grids have been evaluated for use in enhancing trafficability across soft ground and across sand beaches (Webster 1979, 1980, and Webster et al., 1978). The result of this work indicates that benefits are to be gained through grid reinforcement of soil layers. As a result of this and other previous research, tests are currently being planned wherein structural grids will be placed in a simulated crater and evaluated for their effectiveness in replacing some of the required compaction effort.

Reinforcing fabrics (geotextiles)

21. Research at WES (Webster 1979, 1980 and Kinney and Barenberg 1979) and by other agencies, including private industry, has resulted in the gaining of popularity of reinforcing fabrics of various types. These fabrics, commonly referred to as geotextiles, are manufactured in various ways and are made of several different materials. Most often they consist of either spun-bonded, woven nylon, or polypropylene materials and can be readily rolled onto a soil surface. It has been shown (Kinney and Barenberg 1979) that the chief benefit of these geotextiles is their effectiveness in maintaining segregation between soft-soil layers and overlying-granular layers.

22. Considerable research was conducted at WES in the 1960's and 1970's that showed the benefits of soil encapsulation using these geotextiles in combination with an asphaltic sealant (Burns and Barber 1969). The utilization of geotextiles in bomb-crater repair shows some promise for reinforcing subgrade materials and thereby reducing compaction requirements. Further consideration will be given to evaluation of geotextiles in future tests.

Reinforcing Mesh

23. Another innovative and promising concept of earth reinforcement is the use of reinforcing mesh for conventional layered reinforcement by absorbing tensile stresses, and for maintaining segregation between layers. One prime candidate for field evaluation in this program is an expanded polypropylene mesh produced by Gulf Canada, Ltd. (1981). This material consists of a sheet of high-strength polypropylene that has been punched and stretched in two directions to form a polypropylene mesh. The mesh size varies from 1/4 to 3 in.* square. Field tests by the Gulf Canada, Ltd., have resulted in claims that this high-strength polymer reinforcing mesh is effective in enhancing load-bearing capacities of granular layers over soft soils. A field evaluation of this material is planned to evaluate its effectiveness in reduction of compaction requirements. Figure 1 (Lane 2) illustrates the manner of installation of reinforcing mesh (Netlon) in a test item. As shown, the Netlon

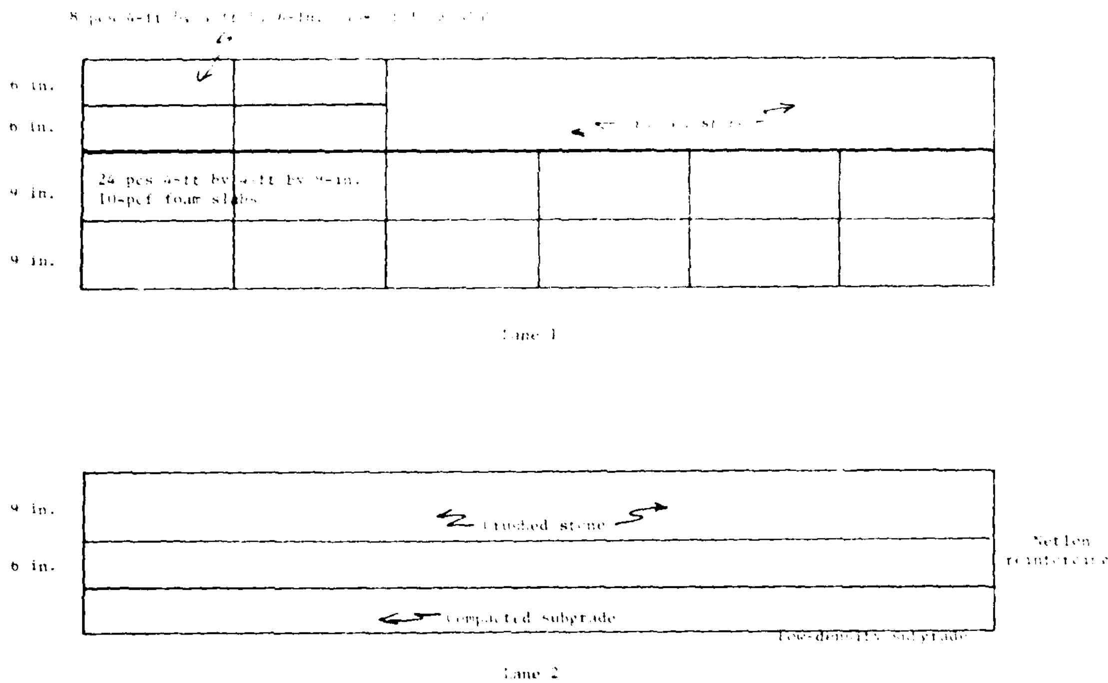

Figure 1. Profile of Lanes 1 and 2 of a test item containing expanded foam and reinforcing mesh

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

will be placed at the top of four respective 6-in. lifts of subgrade material. The pavement will consist of the current crushed-stone interim solution.

Expanded Foams

Concept

24. The previously discussed concept of utilizing synthetic materials to eliminate the need for compaction is being pursued through the use of precast expanded foam blocks. Although the scope of Phase II addresses the subgrade, the expanded-foam technology has also introduced the concept of expanded-foam paving slabs. Therefore, both subgrade and pavement are technologically included in the expanded-foam concept. Expanded foams are currently available in a wide range of strengths, thereby providing the possibility of using such materials not only for subgrades, but as pavement elements also. Figures 2, 3, and 4, respectively, illustrate the compaction-elimination concept of foamed plastic subgrade in combination with different pavement types. Figure 2 illustrates the foamed plastic subgrade in combination with either high-density foamed plastic or portland cement (PCC) precast slabs. Figure 3 shows a foamed plastic subgrade used to support a crushed-stone pavement. Finally, Figure 4 shows the foamed plastic subgrade in combination with heavy-duty airfield landing mat. Figure 1 (Lane 1) illustrates the current plan for evaluation of the performance of expanded foam. As illustrated, a relatively low density foam will be used as a subgrade material to support high density foam pavement slabs, as well as crushed stone.

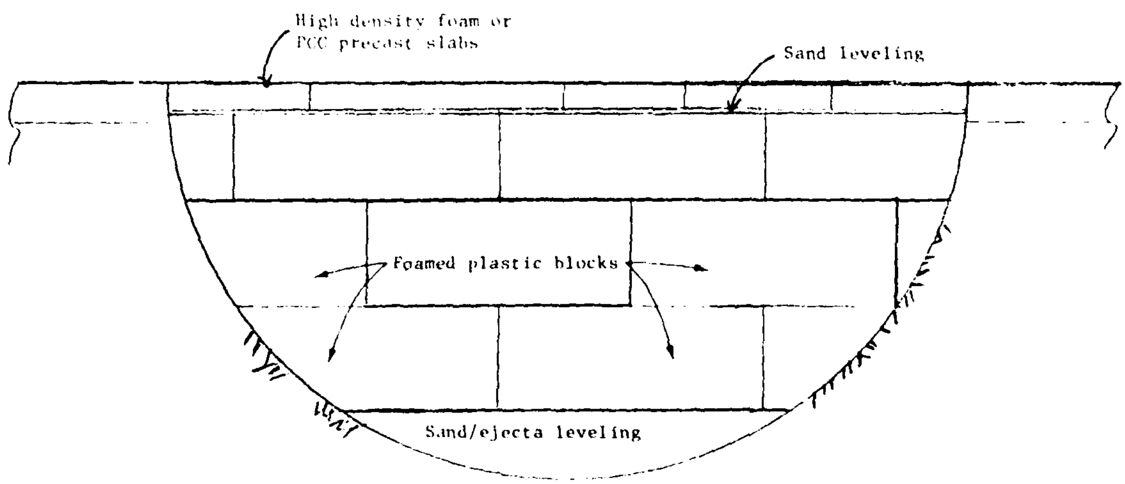


Figure 2. Foamed plastic subgrade with high-density foam or PCC pavement

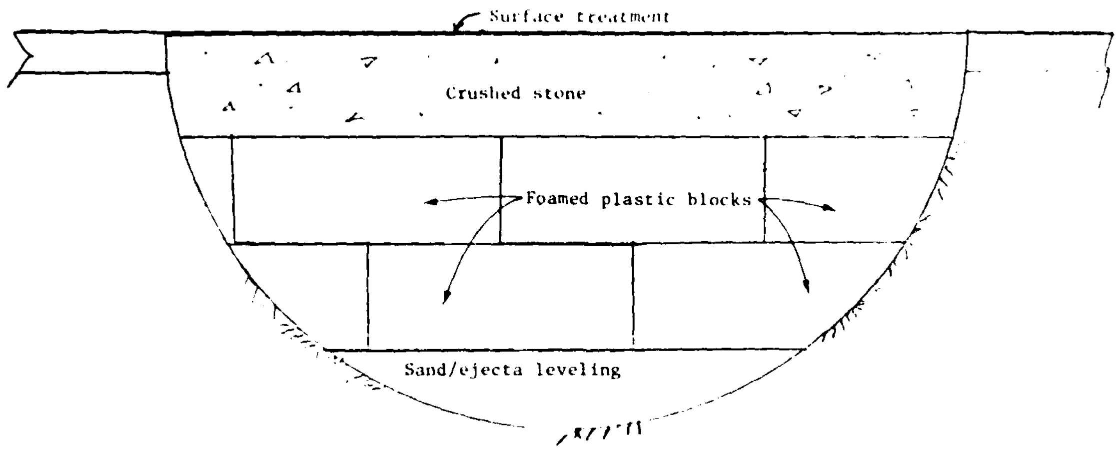


Figure 3. Foamed-plastic subgrade, crushed-stone pavement

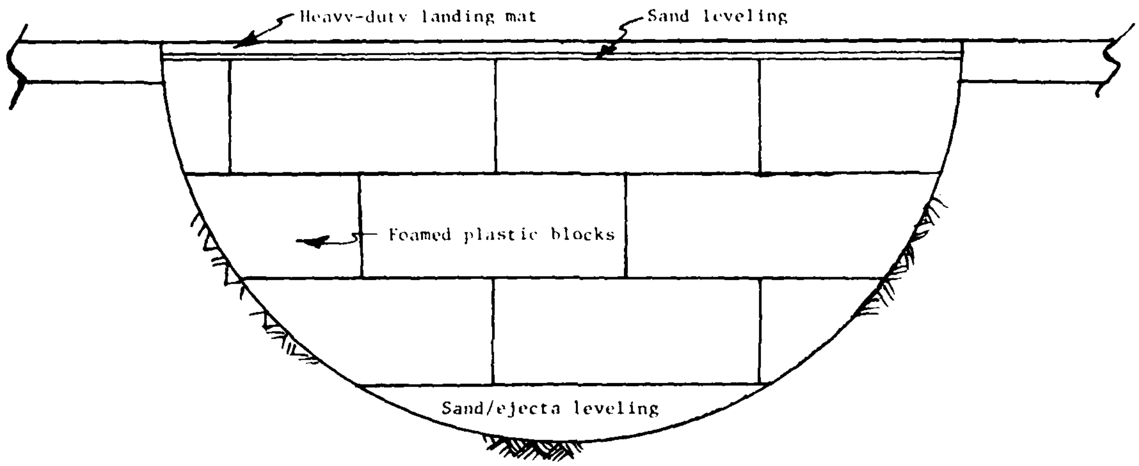


Figure 4. Foamed-plastic subgrade, heavy-duty landing-mat pavement

Description

25. The expanded foams to be used in this evaluation are CO_2-blown rigid polyurethane foams formulated for molding into desired shapes for various purposes. The density of these foams and, thus, the structural properties of precast foam elements can be modified significantly during the mixing and blowing of the components. Two respective densities have been ordered from the Upjohn Co. to conduct the pilot tests, as shown in Figure 1. The foam blocks that are to replace the subgrade are 4-ft-square blocks, 9 in. thick, and will be stacked for a total depth of 18 in. This "lightweight" foam has a bulk density of approximately 16 pcf and a compressive strength of approximately 300 psi. Although detailed information is difficult to obtain on the

various types of foam, the modulus of elasticity is apparently approximately 160,000 psi.

26. The precast-foam slabs are to replace conventional slabs in the test. They will be supplied in 4-ft- by 4-ft- by 6-in.-thick blocks. This high-density foam has a bulk density of approximately 40 pcf and a compressive strength of some 800 psi. The modulus of elasticity is approximately 300,000 psi. A special dewatering process has made it possible to achieve these relatively high densities in modern foams. This particular foam, known as syntactic foam, was developed under Government contract in studies regarding aircraft radar shields.

Procurement

27. Procurement of both types of foam blocks has been difficult chiefly due to manufacturer problems in mold manufacture and in achieving uniformity in the individual castings. It is presumed, at this point, that such problems could readily be solved in any mass-production operation. The cost of these materials is extremely high. Test quantity costs range up to $6000 per cubic yard for the high-density foam. Such costs are prohibitive for large quantities necessary to repair a badly damaged airfield but would be considerably less and, hopefully, tenable in large quantities.

Testing

28. Field and laboratory tests are planned to evaluate the foamed-subgrade and pavement materials. The materials will be evaluated in terms of conventional rigid-pavement criteria. Additionally, ease of placement will be evaluated in order to determine the overall effectiveness of the concept. If this pilot test indicates that the foamed subgrade and pavement concept is feasible, more extensive evaluation will be planned and conducted to develop a quantitative criterion for this use. Since design criteria do not exist, the design for the foamed test section was approximated using existing rigid-pavement methodology.

Other Concepts

29. Although they are not scheduled for testing at this time, other concepts have been generated as a result of this effort. These concepts are a result of the search for materials and methods that effectively reduce or

eliminate the need for compaction and are briefly described in the following paragraphs.

Lightweight modules

30. Lightweight foam pavement and fill slabs have previously been discussed. However, an extension of that concept and an extension of the landing-mat concept produces the idea of a heavy-duty lightweight module that behaves similarly to a rigid pavement. Figure 5 illustrates the employment of a general purpose lightweight module used both as a pavement component and as subgrade backfill. A series of such modules interconnected in a manner to provide for moment transfer between elements could provide for a universal module suitable for repair of most large craters. The initial concept of a module includes a heavy-duty skin, rigid core, and double connectors on all sides. This element could then be considered as a very thick, double connected landing mat, the thickness of which would be capable of providing for rapid backfill as well as a rigid pavement system. Developmental work would essentially consist of production of a test quantity of the modules, field evaluation, and redesign as necessary.

Lightweight containerized pavement modules

31. The lightweight containerized pavement module (LCPM), illustrated in Figure 6, is an extension of the previously described pavement module. In this case, all necessary equipment and materials to produce a foamed-in-place subgrade are contained within the hollow, lightweight modules. Such a system provides for a completely self-contained kit requiring minimal ancillary items to complete the repair. Although this concept is ambitious in nature and obviously would require extensive developmental research, the concept represents a significant, much needed breakthrough in crater repair.

Crater bridging

32. Bridging a crater removes such constraints as the availability of backfill material, material type or condition, moisture conditions, and environmental problems. Admittedly, bridging of a crater appears to be a "last resort" type of concept when considered in comparison to other more rational approaches. However, if the more rational approaches do not produce successful solutions, bridging is a possible research potential. In order to illustrate the crater circumvention phenomenon, two concepts are given in the following paragraphs.

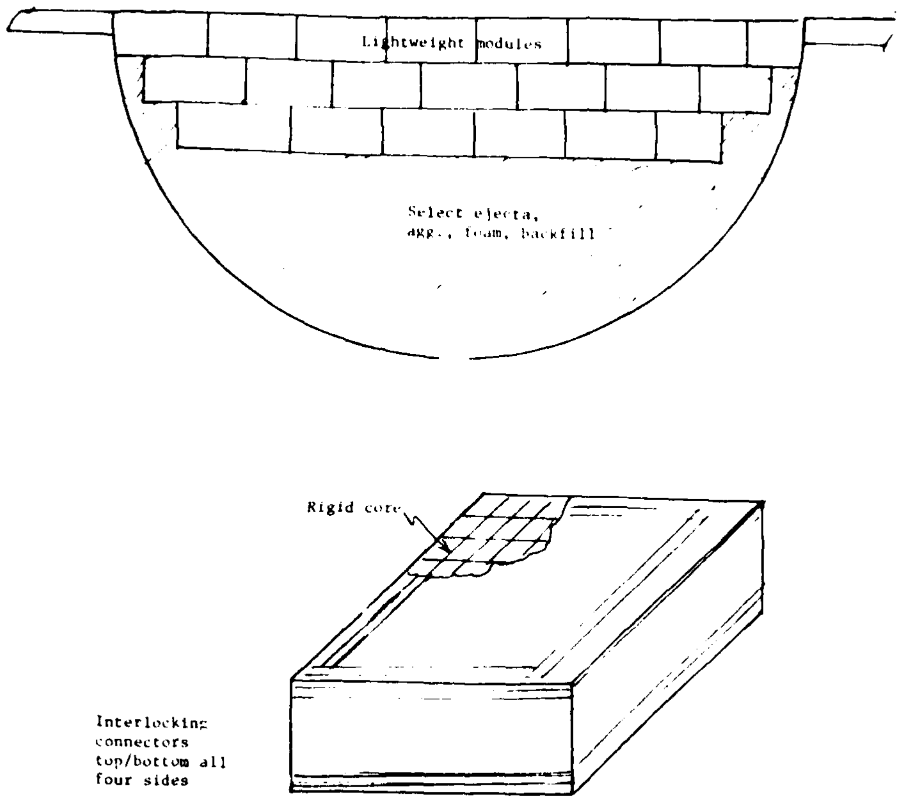


Figure 5. Lightweight modules

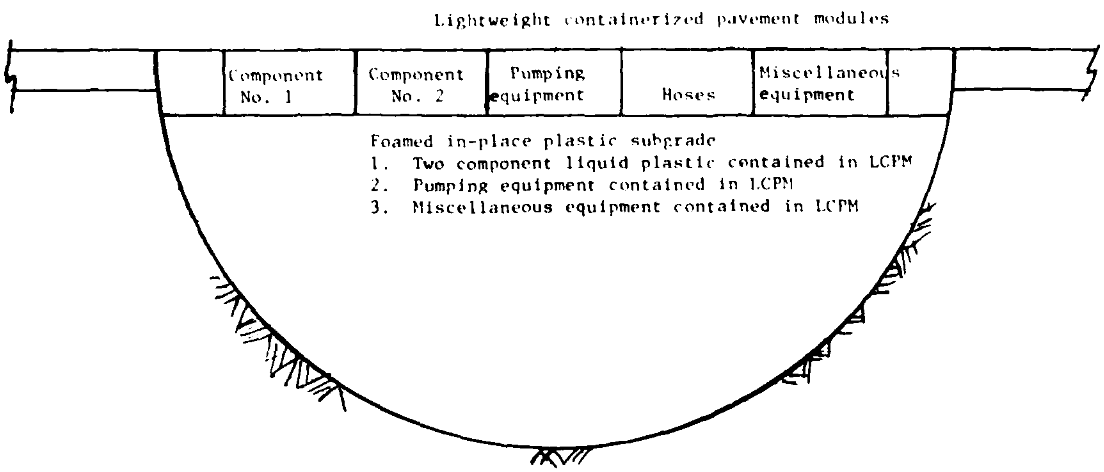
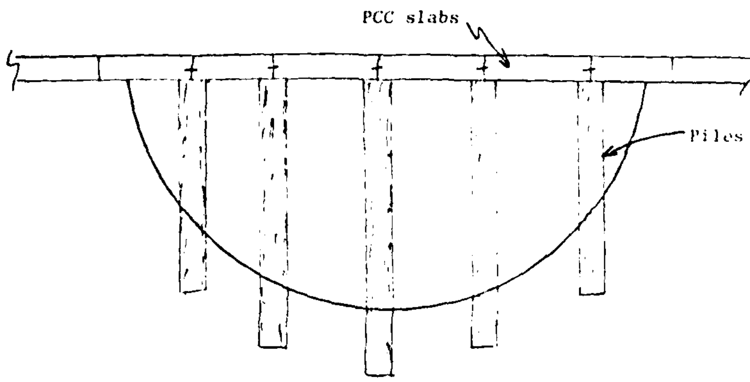


Figure 6. Lightweight containerized pavement modules and foamed-in-place plastic subgrade system

Pile support

33. Figure 7 illustrates the concept of using piles to support precast slabs in order to bridge an unfilled crater. Although the illustration indicates a conventional pile system, several variations are possible using various materials and arrangements, as indicated in the listing in Figure 7.



Pile Concepts

Conventional

Wood
Steel

Non-Conventional

Landing Mat
- Single
- Double
- Box-section
- H-section
- Triangular section

Bearing Cap

Refusal
P versus Δ

Pile Spacing

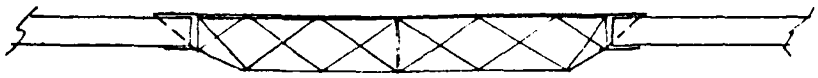
PVT type
Pile bents
Pile cluster
Singular

Spacing Template
(leave in place)

Figure 7. Crater circumvention using piles

Free-span bridging

34. The free-span bridging concept, shown in Figure 8, is based upon hasty bridging equipment such as the current Bailey bridge. The procedure would include a pavement of some type supported by a truss substructure interconnected with adjacent slabs. As in the case of pile support, this system enables the user to avoid special problems such as environment and material types that prevent effective conventional backfilling procedures from being effective.



Concepts

1. Inverted Bailey-type segments
2. Segment dimensions = multiples of slab size
3. True free span or partial support
4. Total support concept
   a. Lightweight webbed interconnecting modules acting as precast slabs
   b. Trim modules to fit crater
   c. Post-tension bottom side
   d. Grout or foam leveling

Figure 8. Crater circumvention using free-span bridging

Multilayer landing mat

35. The employment of multiple, interconnected layers of heavy-duty airfield landing mat, oriented in alternately opposing directions could provide for a rigid pavement system. Such a lightweight rigid system, shown in Figure 9, could significantly reduce the compaction or performance requirements for a subgrade. Since heavy-duty airfield landing mat is currently available in the inventory, evaluation of this system and (if successful) implementation could be readily achieved. The concept includes the shear-resistant interconnection of three or four respective layers, using an appropriate connecting system to form a rigid-pavement layer. The chief research effort would consist of developing a rapid and effective layer-connecting system.

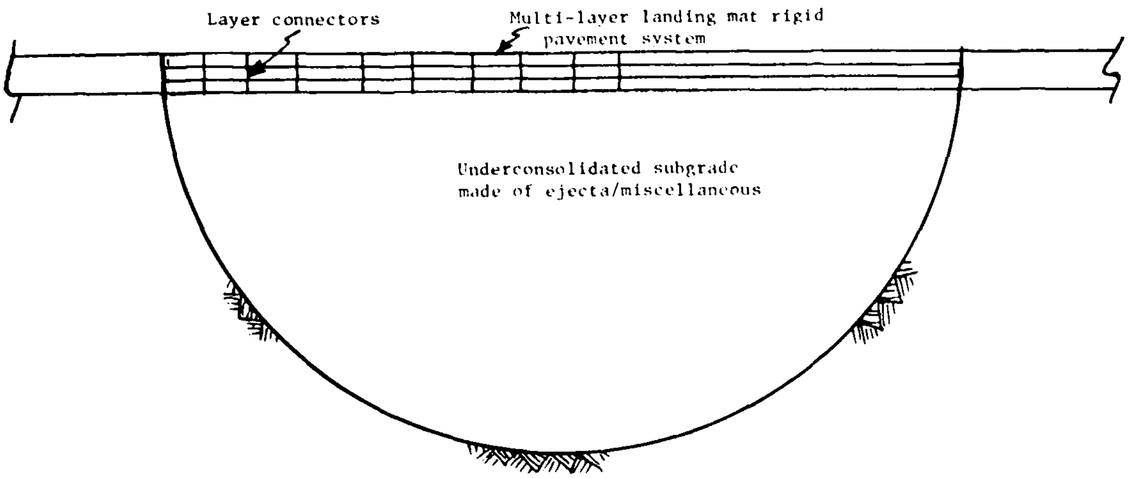


Figure 9. Multilayer landing mat rigid-pavement system

Roller-compacted concrete

36. The recently developed procedure for construction using roller-compacted concrete gives rise to another crater-filling potential. Roller-compacted concrete is essentially described as a high-strength plant-mixed soil cement or a very dry (zero slump) portland cement concrete that is placed and lightly compacted in lifts. The concept of filling a crater with this material and quickly compacting the top portion prior to hydration will be evaluated. The possibility of using rapid setting varieties of portland cement to accelerate the operation will be further evaluated.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

37. As a result of the investigative research and concept formulation that has been conducted to date under Phase II of REREPS, the following conclusions appear warranted:

- a. A significant reduction in current rigid or flexible pavement compaction requirements for backfill of a crater is not feasible and does not warrant further investigation.
- b. The concept of reduced compaction for conventional pavements through the use of current criteria for heavy-load pavements over soft soils is a possible alternative to in-crater compaction.
- c. Specialized, highly competent in-crater compaction equipment is essential for the compaction of crater backfill to support conventional pavements.
- d. The concept of compaction elimination or significant reduction by using synthetic backfill and pavement materials, earth reinforcing, lightweight modules, and crater-spanning techniques is a potential solution to the crater-repair problem.
- e. The employment of pile foundations or free-span bridging systems is a potential solution.

Recommendations

38. As a result of the findings of this study and of the conclusions reached, the following recommendations are given:

- a. Prototype tests to validate conventional rigid and flexible pavement design over low-strength subgrades in craters should be conducted.
- b. The concept of utilizing synthetic materials, earth reinforcing, and bridging concepts to eliminate the requirement for compaction should be pursued through developmental research.
- c. The use of roller-compacted concrete to reduce compaction requirements and to serve as a paved surface should be further investigated.
- d. Liaison should be established and maintained with major heavy-equipment manufacturers to promote the development of competent in-crater compaction equipment.

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